UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

CONVERSION TECHNIQUE FROM 2D TO 3D MODEL FOR A SHAPE–CHANGING AIRCRAFT SLAT MECHANISM

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CONVERSION TECHNIQUE FROM 2D TO 3D MODEL FOR A SHAPE–CHANGING AIRCRAFT SLAT MECHANISM

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in
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DECLARATION

I declare that this thesis entitled "Conversion Technique From 2D To 3D Model For A Shape–Changing Aircraft Slat Mechanism" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Mohammad Hazrin bin Ismail

Date : 23/11/18

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : ....

Supervisor Name : Dr. Shamsul Anuar Bin Shamsudin

Date : 23/11/18

DEDICATION

To my beloved mother and father,

And my siblings.

You all made everything worthwhile.

My great gratitude for Dr Shamsul Anuar Shamsudin.

ABSTRACT

Airframe noise reduction is a topic being investigated for the well-being of people living close to airports. This type of noise can occur between the high-lift systems and main body of the airfoil. The proposed shape-changing mechanism is an alternative to reduce airframe noise by eliminating the gap during deployment of the high-lift systems. This work presents a new design of the 30P30N wing, which focusses on installing a shape-changing slat into the systems. This work applies a chain of rigid body wing segments connected by revolute and prismatic joints that are capable of approximating a shape change defined by a set of morphed slat design profiles. The [***C M C***] slat segment design was created as a result of optimised segmentation process using the *ShapeChanger* software where ***C*** is a constant curvature segment that may change length, while ***M*** is a mean segment of fixed length. The XY data are exported into CATIA software through macros command. To achieve a single degree of freedom (DOF), a building-block approach is employed to mechanise the fixed-end shape-changing chain by using Geometric Constraint Programming as an effective method to design the mechanism. Lastly, a small scale three-dimensional model is developed to mechanise the mechanism driven by a single actuator. Related results showed that the shape-changing airfoil that deploys without a gap between the slat and main body, has a pressure coefficient of around -2.0 whereas the conventional one with gap hovers at -1.0. In addition, the values of Sound Pressure Level (SPL) were improved by maintaining below 100 dB near the slat portion of the airfoil.

ABSTRAK

*Pengurangan bunyi kerangka pesawat udara menjadi topik utama dikaji untuk kebaikan manusia yang tinggal berhampiran dengan lapangan terbang. Bunyi tersebut terhasil di antara sistem daya angkat tinggi dan badan utama aerofoil. Mekanisme ubah-bentuk telah dicadangkan untuk mengurangkan bunyi kerangka pesawat dengan menghapuskan jurang semasa sistem daya angkat tinggi dalam keadaan tersebar. Kajian ini membentangkan reka bentuk baru sayap 30P30N, yang memfokuskan kepada memasang slat ubah-bentuk baru ke dalam sistem sayap. Kajian ini mengaplikasikan rantaian jasad tegar yang dihubungkan dengan sendi revolut dan prismatik yang mampu menganggarkan bentuk-bentuk profil slat. Rekabentuk segmen slat [C **M** C] telah dihasilkan daripada proses segmentasi optimum oleh perisian ShapeChanger di mana **C** adalah segmen jenis kelengkungan malar serta boleh berubah panjang, manakala **M** pula jenis segmen purata yang mempunyai panjang yang tetap. Data XY kemudian dieksport ke dalam perisian CATIA melalui perintah makro. Untuk mencapai satu darjah kebebasan, pendekatan blok-binaan digunakan untuk menggerakan rantaian ubah-bentuk hujung kekal dengan bantuan Pengaturcara Kekangan Geometri untuk membangunkan mekanisme. Akhir sekali, model skala kecil tiga-dimensi dibina untuk menggerakkan mekanisme yang dipandu oleh penggerak tunggal. Hasil kajian berkaitan menunjukan bahawa aerofoil ubah-bentuk yang menghapuskan jurang di antara slat dan badan mencapai pekali tekanan sekitar -2.0 sedangkan slat konvensional cuma mencapai nilai kira-kira -1.0. Tambahan lagi, nilai Tahap Tekanan Bunyi (SPL) telah ditambahbaik dengan mengekalkan nilai di bawah 100 dB berhampiran slat aerofoil tersebut.*

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LIST OF SYMBOLS

$\boldsymbol{M}$	–	Mean segment type
$\boldsymbol{C}$	–	Constant curvature segment type
s_d	–	Desired piece length for target profiles
C_p	–	Coefficient of pressure
P_∞	–	Static pressure
v	–	Velocity
ZnO	–	Zinc oxide
p	–	Number of design profiles
m_j	–	Number of pieces on target profile j
n_j	–	Number of points on target profile j
c_{j_i}	–	Length of piece i on design profile j
C_j	–	Arc length of design profile j
z_{j_i}	–	A set of i points on profile that j that will be transformed
S_j	–	Arc length of target profile j
s_{j_i}	–	Length of piece i on target profile j
E_{s_j}	–	Mean segment length
$m_j{}^*$	–	Number of pieces on target profile j that minimize ϵ_{s_j}
$n_j{}^*$	–	Number of points on target profile j that minimize ϵ_{s_j}
α	–	Minimum number of pieces per segment
q	–	Number of segment in a chain of rigid body
Q_∞	–	Dynamic pressure
ρ	–	Fluid density
V_∞	–	Velocity of a fluid
M_∞	–	Freestream Mach number
L	–	Number of links
J_1	–	Number of lower pair joints
J_2	–	Number of higher pair joints
v_i	–	The points in the sensed or captured image
c	–	Scaling factor
A	–	Rotation matrix
d	–	Displacement vector
U_i	–	The XY points of reference image
V_i	–	The new coordinates of transformed image

LIST OF ABBREVIATIONS

2D	-	Two–dimensional
3D	-	Three–dimensional
ABS	-	Acrylonitrile Butadiene Styrene
AOA	-	Angle of attack
CAD	-	Computer–Aided Design
CFD	-	Computational Fluid Dynamic
DOF	-	Degree of Freedom
DMU	-	Digital mockup kinematic
ESO	-	Evolutionary Structural Optimization
FDM	-	Fused Deposition Modeling system
GA	-	Genetic Algorithm
GCP	-	Geometric constraint programming
GUI	-	Graphical User Interface
HECS	-	Hyper-Elliptic Cambered Span wing
KMoGE	-	Kutzbach Modification of Grubler's Equation
MEMS	-	Micro-Electro-Mechanical-System
P	-	Prismatic
R	-	Revolute
RP	-	Rapid–prototyping
S	-	Spherical
SMA	-	Shape–Memory Alloy
SME	-	Shape-Memory Effect
SPL	-	Surface pressure level
STL	-	Stereo Lithography file format
VBA	-	Visual Basic for Application

LIST OF PUBLICATIONS

Ismail, M. H., Shamsudin, S. A. and Sudin, M. N., 2016. Kinematic Synthesis of Planar, Shape-Changing Rigid-Body Mechanisms for 30P30N Slat Design Profile. *International Review of Mechanical Engineering (IREME)*, 10(1), pp. 1-6.

Ismail, M. H., Shamsudin, S. A. and Sudin, M. N., 2016. Implementation of ShapeChanger as Preliminary Process to Synthesize a Mechanism in CATIA Software. *ARPN Journal of Engineering and Applied Sciences*, 10(18), pp. 10982-10986.

Ismail, M. H., Shamsudin, S. A. and Sudin, M. N., 2015. Design and Analysis of Rigid-Body Shape-Change Mechanism for Aircraft Wings. *Jurnal Teknologi.* 77(21), pp. 1-7.

CHAPTER 1

INTRODUCTION

1.1 Background

Several high-lift systems (which include the flaps and slats) are seen to play a vital role during the take-off and the landing of an aeroplane. However, despite their importance, traditional high-lift systems have problems that could affect their performance. When the high-lift systems are introduced on aeroplane, these systems incorporate a complex mechanism to mechanize thus increase the weight of the wings. As a result, the capability of for the aeroplane to achieve maximum lift level is decreased (Van Dam, 2002). Multi-element aerofoils consist of three essential elements, where one forms the main aeroplane body and the other two elements form the high-lift system.

According to some earlier studies, landing gears and high-lift systems are mainly responsible for the airframe noises (Dobrzynski et al., 2002; Konig et al., 2009; Dobrzynski, 2010). In another study, Khorrami (2003) investigated the noise production mechanisms associated with the slats. The researcher mainly focused on the vital role of the computational simulations in the understanding and identification of the noise source. Furthermore, some authors also observed that the gaps present between the solid walls of the aeroplane (main body) and the high-lift systems (including flaps and slats) resulted in the airframe noises (Weisshaar, 2006; Rodriguez, 2007; Barbarino et al., 2011). An example describing the continuous shape-morphing wings using the rigid-body mechanism has been shown in Figure 1.1.

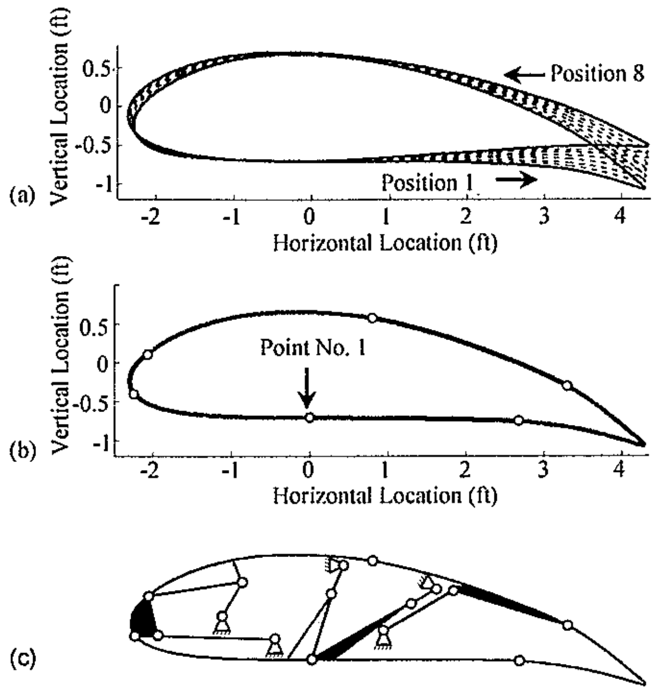

Figure 1.1: Other shape-changing wings (Zhao et al., 2012).

The problems related to the high-lift system need to be resolved for improving their performance. One solution includes the application of the shape-changing technique on the aeroplane wings which uses the rigid-body components which establish a closed-chain that is linked by the revolute joints and eliminate the gap present between the major aeroplane components (Zhao et al., 2012). Also, Shamsudin et al., (2013) suggested and developed a new shape-changing wing between E420 and E850 aerofoils as shown in Figure 1.2.

Ismail et al., (2015) carried out two–dimensional (2D) computational analysis for both conventional and shape–changing 30P30N airfoils to study the aerodynamic performance. The results show that gap between the slat and main body not only affects the region close to the main body but also the stretches further toward the rear flap undergo other effects. The shape-changing airfoil covering the gap between the slat and main body possesses many benefits including lowering static pressure that can affect noise generation. As the air flew through the slat to main body, the values of static pressure and velocity are constant and controllable at the specified value. The shape-changing airfoil develops higher suction pressure coefficient of around -2.0 on slat area whereas the conventional airfoil only remains at -1.0. The value of Sound Pressure Level (SPL) at the area of slat for both airfoils show the shape-changing airfoil has constant high and low SPL value at upper and lower surface while conventional airfoil has inconsistent SPL value at both surfaces. The SPL values for shape-changing airfoil were maintained below 100 dB near the slat area.

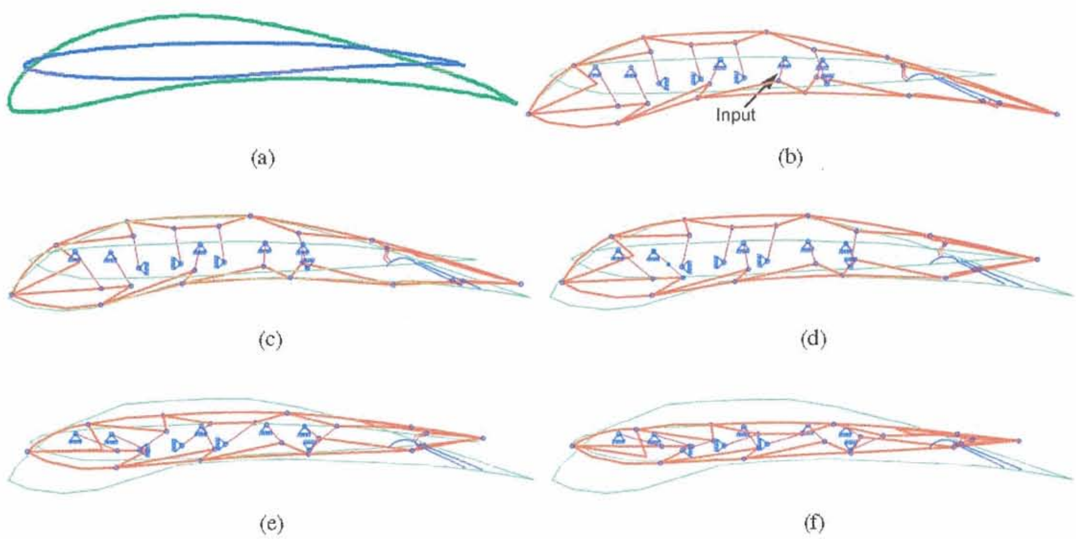

Figure 1.2: Shamsudin's (2013) suggestion for a rigid body shape-changing wing.

1.2 Problem Statement

As the shape–changing wings improve the aerodynamic performance of the wing, this results motivate other researchers to further study on these mechanisms. Despite extensive research on shape-changing technique have been discovered, it is clear that a thorough study on the shape-changing technique on aeroplane wings usage is still not complete. Most works only focus to develop a mechanism only in two–dimensional (2D) solution because it is difficult to translate the 2D design into three–dimensional (3D) mechanism. So, the capability of shape-changing technique mainly tested on the simulation only.

In order to simplify the mechanism, a one degree of freedom (DOF) mechanism is considered. Thus the aerofoil design was optimised after decreasing the three-element aerofoil to a two-element aerofoil where, the main body and the shape-changing slat were combined together to form a single body. In addition, a systematic and thorough study need to be conducted where the main focus is to develop a three–dimensional (3D) model of shape-changing aeroplane wings.

1.3 Objectives

The main objectives of this study are:

a) To develop a shape–changing rigid-body slat mechanism of an aircraft wing with different arc lengths.
b) To devise a process to convert 2D data from MATLAB software into 3D data for use in CATIA software.

1.4 Scope of the Project

After setting the objectives, the scope of this study has been described below and includes the following constraints:

a) This work was carried out using computer simulations with MATLAB and CATIA V5 as the primary engineering tools.
b) Only focuses on slat mechanism, all profiles were based on the 30P30N, which obtained from a respected aerofoil database.
c) The application of GCP to mechanize the new slat mechanism.
d) Only develop a small scale prototype model.